# PROPERTIES OF ARTIFICIAL DIELECTRICS AT RADIO FREQUENCY

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**ABSTRACT.** Dielectric constants and loss tangents of several metal powder artificial dielectrics have been determined in the radio frequency region 126 Kc/s. The results thus obtained have been utilised for the calculation of dielectric conductivities. The results show that amongst the artificial dielectrics studied, the antimony dielectrics have greater dielectric constants while their loss tangents are smallest. These characteristics of antimony dielectrics shall be of special advantage wherever the artificial dielectrics are to be used.

## INTRODUCTION

The development of the artificial dielectrics has been the subject of much theoretical and experimental investigations during the past few years. For obvious reason artificial dielectrics play an important role in the development of modern electronic engineering. Kelly (1953) measured the dielectric properties of metal powders in paraffin wax using microwave technique. Vogan (1952), Negebauer (1952), Peppiatt (1953), Meyer *et al.* (1956) and Mikaelian (1955) have reported on the same type of work. The dielectric properties of such a media are affected by (a) volume fraction of the metal powder (b) size and shape of metal particles (c) binding medium and (d) frequency of operation. Recently Pradhan and Gupta (1961) have shown that the effective dielectric constant also depends on the elemental spacing distribution and size distribution of particles. The effects of binding medium and frequency of operation are not of much importance and the relation between the two can be given as,

$$K_{eff} = KF(\alpha) \qquad \ldots \quad (1)$$

where $F(\alpha)$ is an algebric function of $\alpha$, the polarizability of metal particles. It means that the effective dielectric constant of medium ($K_{eff}$) is directly proportional to that of vehicle medium ($K$). The frequency dependence on dielectric constant shall occur if the Debye's (1909) condition

$$a = \frac{\lambda_0}{7.255} \qquad (2)$$

is satisfied by the particle size; a being the semi-major axis of the particles and $\lambda_0$ is the wavelength in meters. For all practical purposes $\lambda_0$ corresponds to sub-millimeter region.

The present work was undertaken with a view to observe the effects and suitability of these artificial dielectrics at radio frequencies.

## EXPERIMENTAL PROCEDURE

Paraffin wax ($\epsilon = 2.25$ andt an $\delta = 0.0002$) used as the binding medium, was melted and metal powder was poured into this molten wax and the mixture was stirred until it is solidified. This solid mixture was cooled to a sufficiently low temperature with the help of a freezing mixture, the mass getting quite crisp, it was reduced to fine powder and then dessicated for 36 hours. The fine powder was put into a specially designed brass cast (Fig. 1) which was slowly heated from

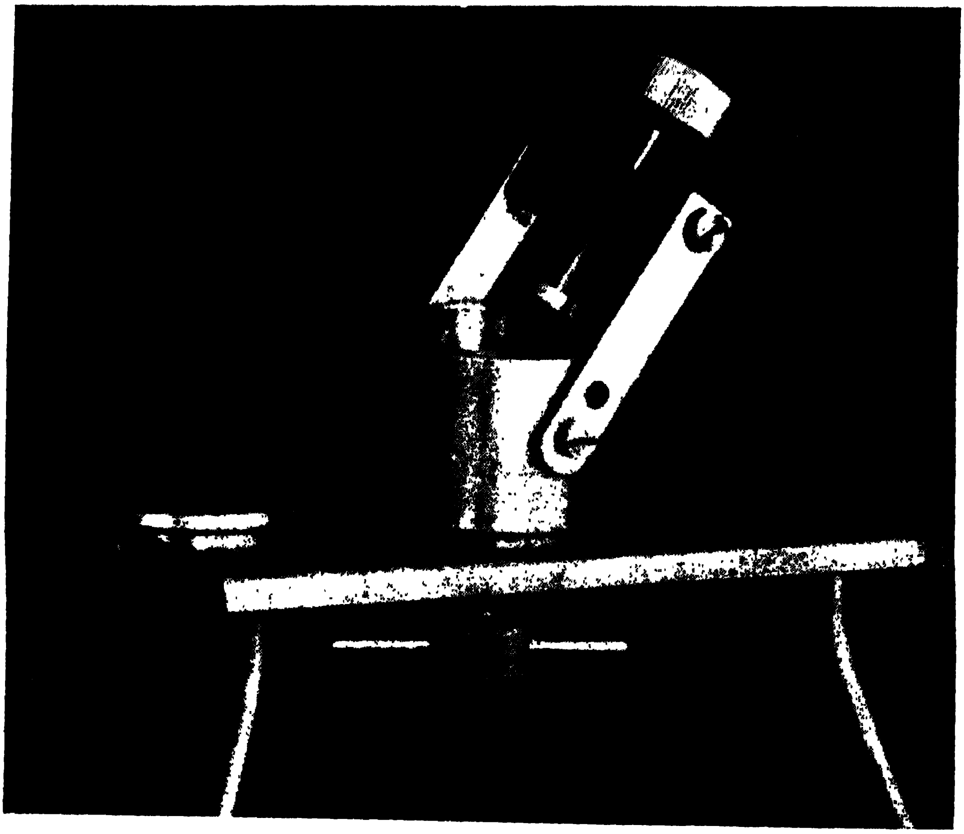


Fig. 1. Cast for moulding the samples.

outside. The specially designed cast is capable of exerting heavy pressure to the mixture, thus providing a sample free of air and giving a definite shape to it. It was then cooled and the sample taken out. Samples thus moulded were cut to desired thickness. The technique provided samples having homogeneous distribution of metal particles.

Exact percentage of metal powders in different samples were determined as follows :

The sample was dissolved in hot liquid paraffin oil and centrifuged, the solid mass was then further dissolved in benzene, filtered and dried. The process was repeated twice, the mass of metal powder was weighed and the percentage calculated.

Hartshorn's (Hartshorn and Ward, 1936) method for the measurement of dielectric constant and loss tangent at radio frequencies was used. The adjustments were made by means of two micrometer condensers, one being a plate condenser in which the sample was inserted and other the cylindrical condenser of linear law and of very small range, which served to measure the sharpness of resonance. Both permittivity and power factor could be obtained as the ratio of the capacitance readings, frequency is not involved in their calculation.

The dielectric constants and loss tangents of different samples were determined at 126 Kc/s as described in detail by Sharma (1960), Pradhan and Sharma (1960) and Sharma and Gupta (1963).

The dielectric constant $K$ of a solid sample is given by

$$K = \frac{3.6 C_s t}{r^2} \qquad \dots \quad (3)$$

where $C_s$ is capacitance of the sample in $\mu\mu F$, $t$ is the thickness of the sample and $r$ is the radius of electrodes (2.5 cms.).

The loss tangent is given by

$$\tan \delta = \frac{\Delta C_1 - \Delta C_0}{2 C_s} \qquad \dots \quad (4)$$

where $\Delta C_1$ is the capacitance change corresponding to half of the maximum deflection with sample in between the two copper electrodes and $\Delta C_0$ is the capacitance change corresponding to half of the maximum deflection without the sample.

Dielectric conductivities were calculated by the following formula

$$\sigma = 0.0053024 \left( \frac{\pi K \tan \delta}{\lambda} \right) \qquad \dots \quad (5)$$

where wavelength $\lambda$ is in meters.

## RESULTS AND DISCUSSIONS

Figs. (2) and (3) and Tables I and II show the variation of dielectric constants and loss tangents of copper, antimony, zinc and calcium metal powder artificial dielectrics.

Microscopic examination of these metal particles showed that copper and antimony particles have irregular form ($20\mu \times 10\mu \times 7\mu$ on average for copper and

$6\mu \times 3\mu \times 2\mu$ for antimony) and zinc and calcium particles have the form of spheres. As the polarizability of sphere is minimum because of the smallest surface area for a given volume, it is expected that copper and antimony dielectric shall have a higher dielectric constant as compared to zinc and calcium dielectrics for the same

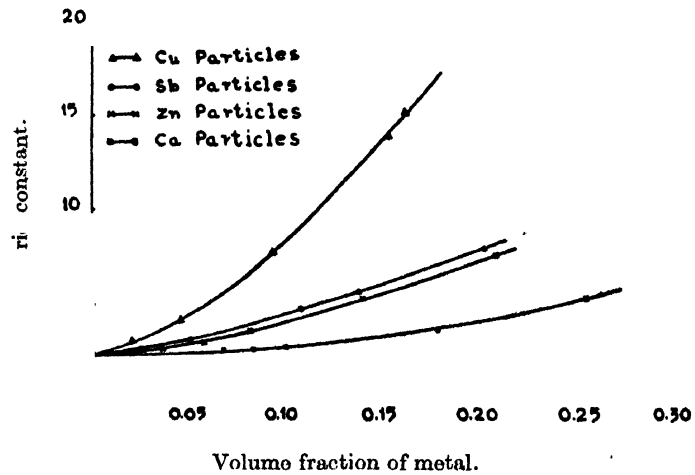



Fig. 2. Variation of dielectric constant of metal powder artificial dielectrics with concentration.

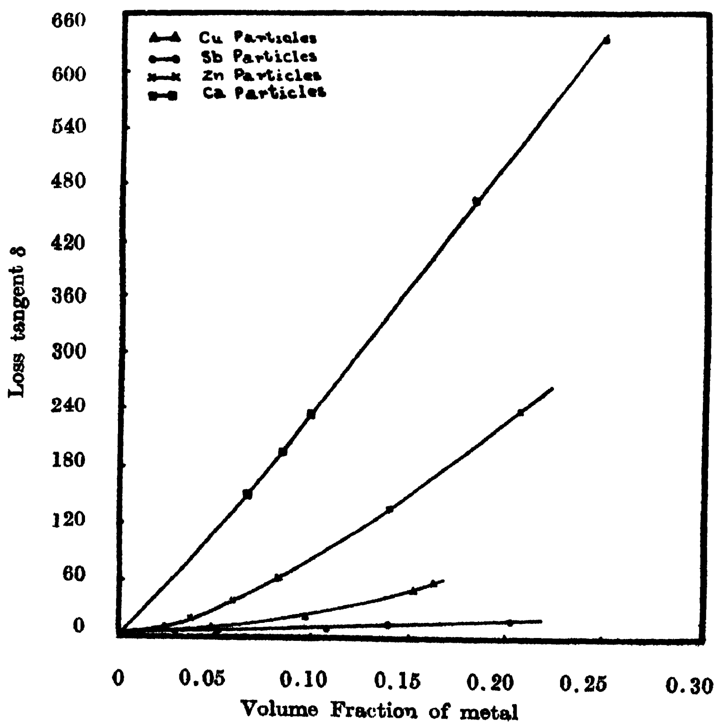



Fig. 3. Variation of loss tangent δ of metal powder artificial dielectrics with concentration.

TABLE I

Variation of dielectric constant of Metal powder artificial dielectrics with concentration

| Copper | | Antimony | | Zinc | | Calcium | |
|---|---|---|---|---|---|---|---|
| Fractional Volume | $K$ | Fractional Volume | $K$ | Fractional Volume | $K$ | Fractional Volume | $K$ |
| 0.021 | 3.066 | 0.025 | 2.801 | 0.038 | 2.916 | 0.069 | 2.772 |
| 0.048 | 4.182 | 0.052 | 3.200 | 0.060 | 3.300 | 0.085 | 2.864 |
| 0.096 | 7.600 | 0.107 | 4.620 | 0.083 | 3.560 | 0.101 | 2.990 |
| 0.154 | 13.570 | 0.138 | 5.586 | 0.140 | 5.305 | 0.180 | 3.715 |
| 0.164 | 14.990 | 0.204 | 7.780 | 0.209 | 7.496 | 0.253 | 5.376 |

TABLE II

Variation of loss tangent of metal powder atrificial dielectrics with concentration

| Copper | | Antimony | | Zinc | | Calcium | |
|---|---|---|---|---|---|---|---|
| Fractional Volume | tan $\delta \times 10^4$ | Fractional Volume | tan $\delta \times 10^4$ | Fractional Volume | tan $\delta \times 10^4$ | Fractional Volume | tan $\delta \times 10^4$ |
| 0.021 | 3.480 | 0.025 | 3.473 | 0.038 | 22.400 | 0.069 | 152.560 |
| 0.048 | 7.650 | 0.052 | 4.100 | 0.060 | 39.390 | 0.085 | 195.000 |
| 0.096 | 23.850 | 0.107 | 8.210 | 0.083 | 61.200 | 0.101 | 236.320 |
| 0.154 | 53.340 | 0.138 | 10.550 | 0.140 | 144.800 | 0.180 | 452.200 |
| 0.164 | 60.790 | 0.204 | 20.040 | 0.209 | 234.200 | 0.253 | 632.700 |

TABLE III

Variation of dielectric conductivity of metal powder artificial dielectrics with concentration

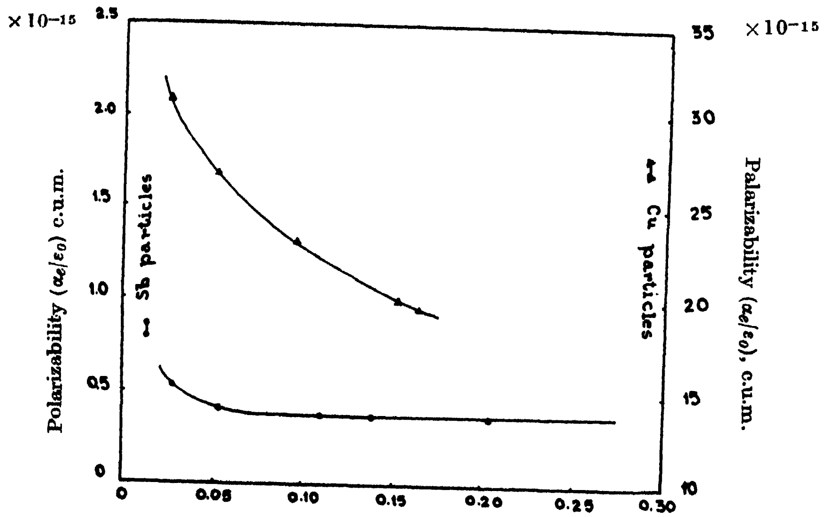
| Copper | | Antimony | | Zinc | | Calcium | |
|---|---|---|---|---|---|---|---|
| Fractional Volume | $\sigma \times 10^3$ (mhos/metre) | Fractional Volume | $\sigma \times 10^3$ (mhos/metre) | Fractional Volume | $\sigma \times 10^3$ (mhos/metre) | Fractional Volume | $\sigma \times 10^3$ (mhos/metre) |
| 0.021 | 7.461 | 0.025 | 6.812 | 0.038 | 45.671 | 0.069 | 295.760 |
| 0.048 | 23.372 | 0.052 | 9.203 | 0.060 | 90.844 | 0.085 | 390.510 |
| 0.096 | 126.770 | 0.107 | 26.430 | 0.083 | 152340 | 0.101 | 494.080 |
| 0.154 | 506.070 | 0.138 | 41.263 | 0.140 | 537.280 | 0.180 | 1174.600 |
| 0.164 | 637.240 | 0.204 | 108.990 | 0.209 | 1227.500 | 0.253 | 2378.600 |

volume fraction. The investigations verify this. The experimental results on copper, antimony, zinc and calcium show that the antimony dielectrics have minimum loss for a given volume fraction than others and still have got greater values of dielectric constant than for zinc and calcium. From the variation curves for the dielectric constants and the losses it can be suggested that the antimony dielectrics are best suited for any work wherever the artificial dielectrics are to be used.

Let us consider the case of antimony in detail. On calculating $\left(\frac{\alpha e}{3\epsilon_0}\right)$ $\{= f/N =$ constant, the volume fraction for spheres$\}$ from the Clausius-Mossotti relation

$$\frac{K_e - K}{K_e + K} = \frac{N}{3}\left(\frac{\alpha e}{\epsilon_0}\right) \quad \ldots \quad (6)$$

and plotting it against the fractional volume (Fig. 4.), it was found that the two have linear relationship, pointing out that the polarizability remains constant




Volume fraction of Paticles.

Fig. 4. Palarizability of antimony and copper particles from Clausius-Mossotti relation.

even at higher volumes although it should have increased due to the agglomeration. The investigations point out that there is no agglomeration in this case. At first sight one would think that this result has been obtained just per chance; but this view was obviated by repeated investigations on samples made afresh. Authors have not been able to find out suitable interpretation why the agglomeration does not take place in case of antimony. One can however suggest that the inter particle force between Sb—Sb is possibly smaller than the binding system.

Polarizability, thus found for antimony is five times greater than that of the sphere and remains constant. It implies, therefore that the shape of these particles on the average remains unchanged even at higher volume fractions (35%) and the dielectric constant of antimony dielectric can be calculated theoretically.

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